Evaluating Hyperspectral and Polarization Properties for Bathymetry and Water Property Estimation in Extremely Turbid Waters

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LONG-TERM GOALS

Riverine operations often require knowledge of water depth and hazards in turbid water environments. The ability to remotely retrieve bottom depths shallower than 0.5 m is critical to the insertion and extraction of personnel as well as navigation hazards which can hamper routes. Various passive methods have been employed to retrieve optical and bottom characteristics in clearer coastal environments using hyperspectral imagery (Lee, 2001), but these methods have not been evaluated for the extreme cases when multiple scattering is present. At this point the shape of the phase function and whether attenuation decreases are due to scattering or absorption are a critical factor. The Fleet requires that remote estimations of bathymetry in turbid waters be made. The goal is to determine whether or not hyperspectral imagery with the addition of polarization can improve the ability to discern bathymetry in the turbid water environments. How to extend the use of passive imagery in general for penetration into a turbid water column is a goal that impacts more than the riverine Special Forces Operations but also MCM and Port and Harbor Security.

OBJECTIVES

Two critical questions arise if one is to determine the limits of hyperspectral imagery for bathymetric retrievals. The first is to determine when a commonly used method “breaks-down” using passive imagery. The second is whether or not detection of the bottom can be improved when additional information, in our case polarization, is added to the imagery. This investigation looks at turbid water with high Colored Dissolved Organic Matter (CDOM) and high scattering to determine whether there is possibilities in retrieving bathymetric information (0.5 meters or more) when multiple scattering dominates and there is very low contrast differences (bottom reflectivity relative to water column).

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The second objective is to determine whether or not the addition of polarization adds significantly to our ability to retrieve bathymetry in these turbid water scenarios.

APPROACH

There are two aspects of this research. The first is to determine when the optimization method of Lee becomes suspect and whether or not this method can be used to determine shoreline features in the turbid water environment. This would be accomplished using a turbid water condition where multiple scattering would be assured over the 0.5 meter desired depth. A target would be lowered and the retrieved depths determined. The second, probably more important, aspect is one in which the river system is modeled using a radiative transfer model to determine the key factors in detecting the bottom in the turbid media and whether or not the polarization adds significantly to our capability. The model is a two-layer system (atmosphere and river) coupled by a smooth dielectric interface with an unpolarized light source above the atmosphere, penetrating the water column to a bottom with known albedo. Given various bottom albedos, viewing geometries, and bottom depths the model would yield information on the Stokes vector/Mueller matrix elements. By varying the bottom depth and albedo and keeping water absorption and scattering, volume scattering function, and the scattering matrix fixed, the vector irradiance, degree of polarization, and the Stokes parameter could be obtained for each source and receiver configuration. From this information the potential use of polarization as well as impact of the multiple scattering on bottom depth retrievals could be evaluated.

WORK COMPLETED

xThe turbid water test area was the Pearl River, MS during a period when there was high absorption and scattering (>7 m^{-1} and 16 m^{-1} for absorption and scattering at 532 respectively). To determine how accurately the hyperspectral optimization could retrieve bottom depths a white dry erase board was positioned at 46 cm and 61 cm below the surface, remote sensing reflectance was measured, and retrieved depths were compared to known depths. A white board was used to enhance the returning radiance. Figure 1 shows a picture of the board at 46 cm depth and the reflectance spectra taken near the board and then at the board. Note the strong signal in the 600 -650 nm portion of the spectrum.

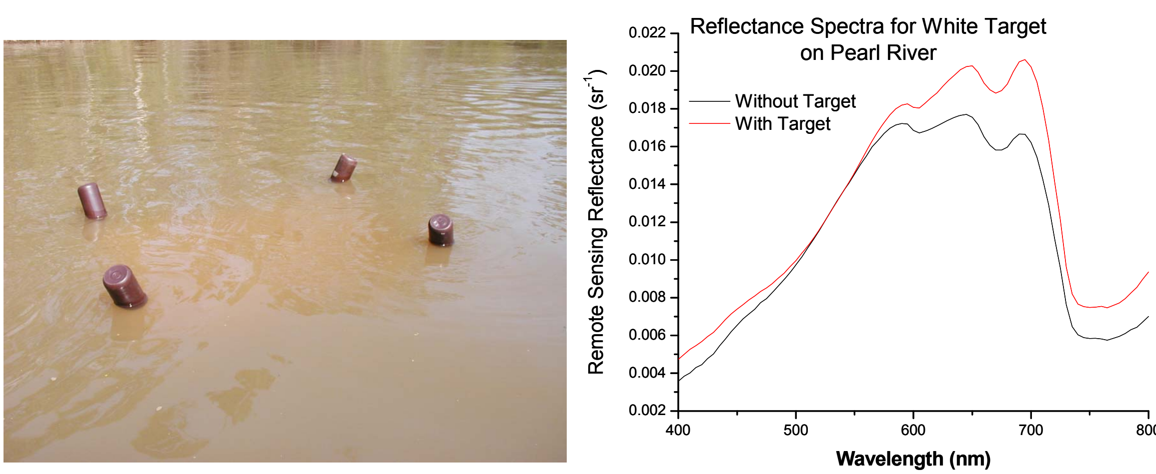

Figure 1: Submerged dry erase board and remote sensing reflectance [left: a picture of the dry erase board 46 cm below the surface with 'c value of 23 m^{-1} at 532 nm; right the resulting remote sensing spectra for area next to board and just above the white board]

The two layered model was run for the above values of absorption and scattering (single scattering albedo of 0.70) assuming a smooth with interaction of the light and the river surface modeled using Fresnel matrices. The river bottom was modeled as a Lambertian reflecting surface with a varying albedo and bottom depth. The source was placed at the top of the model, above the atmosphere. It was assumed to have unit strength and to emit mono-directional, unpolarized light (represented by a Stokes vector for which the first parameter is unity and the rest are zero). The source direction was made to range over a set of polar angles from 30° to 88.5° (as measured from the zenith), in increments of 5°. The source wavelength was set to 550 nm. The receiver, in these simulations, is basically a point at which radiation arrives from a range of directions. These directions are defined by sets of polar and azimuth angles. The polar angles range between 30° and 87.5° (as measured from the zenith), in 2.5° increments, and the azimuth angles between 0° and 180°, in 5° increments. Calculations were made for points at two altitudes; 1000 feet and 3000 feet, respectively matching altitudes of hyperspectral over-flight imagery. The "viewing" directions were similar to the source limits and directionality.

RESULTS

When optimization techniques were used on the white target placed 46 and 61 cm below the surface, the 61 cm (14 optical depths) could not be discerned from background. However at 10 optical depths the target depth was retrieved to within 10% but only after constraining the model by indicating that I knew something was there. Otherwise no unique solution was obtained. Whether or not "spatial" coherence can be used to help in determining whether a solution can be constrained is being considered.

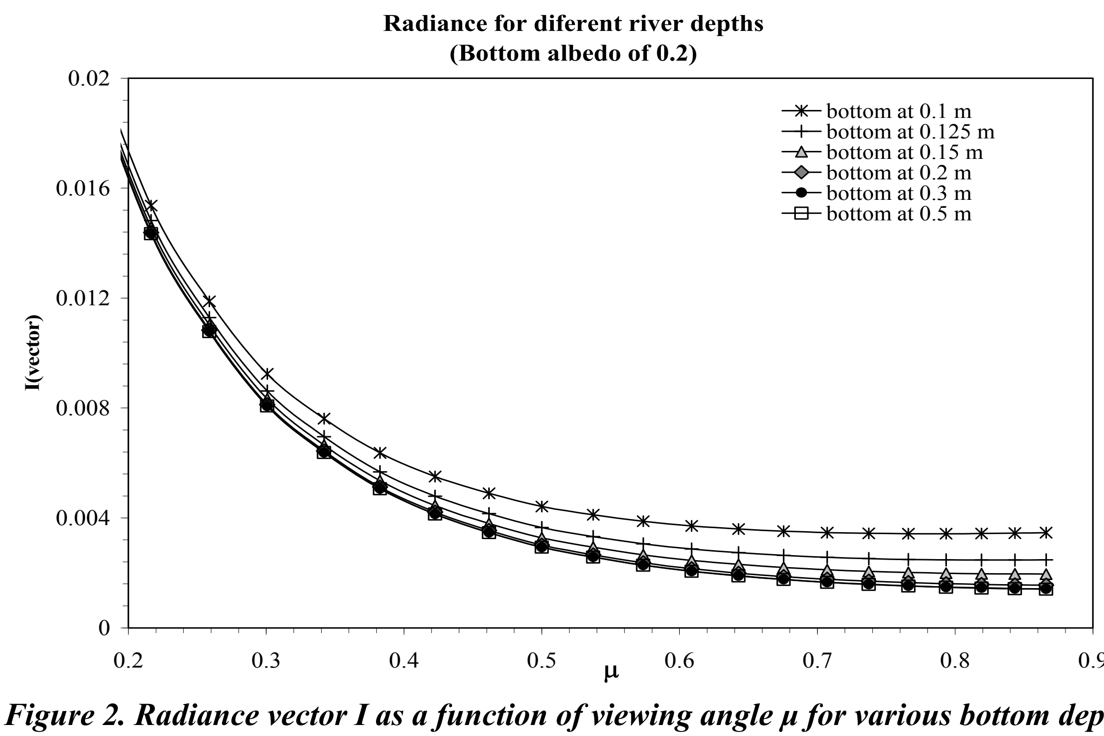

Figure 2. Radiance vector I as a function of viewing angle μ for various bottom depths [graph: model derived radiance when bottom albedo is 0.2 showing bottom still "distinguishable" until 0.2 m for given case, solar angle is 30°]

The vector radiative transfer model was run at bottom albedos of 1.0 and 0.2 (more realistic). The results of the modeling effort showed two points. The first was that with the conditions set for the river system being modeled (Pearl River with absorption = 7 m^{-1} and scattering = 16 m^{-1}, and using the Henyey-Greenstein phase function (0.98 value for the asymmetry factor) then the intensity of the radiance was indistinguishable from between the target (bottom in this case) and the surrounding water by the time a depth of 0.3 meters was reached with the low albedo with only minor improvement with the white high reflectance bottom (Figure 2, solar angle of 30 degrees).

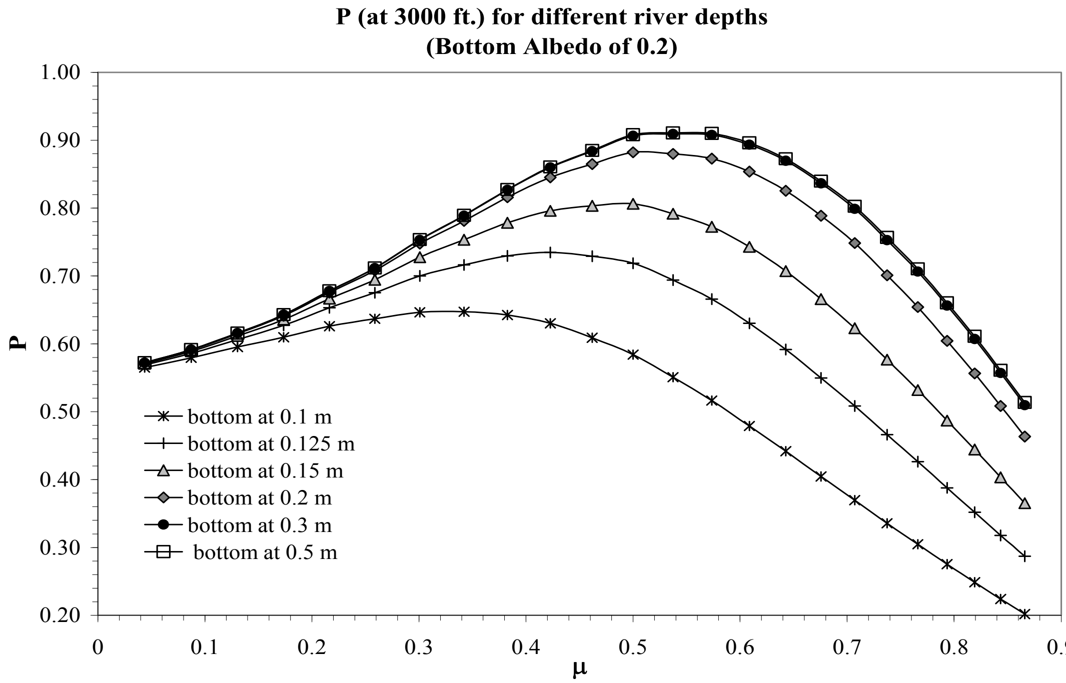

Figure 3. Degree of polarization (P) as a function of view angle μ for various bottom depths [graph: model results show that below 0.3 meters polarization does not help distinguish depth, solar angle at 30°]

In contrast the addition of the polarization information (Figure 3) did an improved job in retrieval of the low bottom albedo high scattering condition. In this case the difference in the degree of polarization was observed to show separation to a depth of 0.3 meters. While this may not seem significant, it is a 50% increase in the radiance only condition. However, the higher unity albedo condition did not appreciably impact either the 0.2 meter or the 0.3 meter limitation depth. But the radiance only will have severe constraints when used by itself in retrieving bottom bathymetry. This is where the full impact of the polarization will be realized. With the low albedo condition and when depth of the river is shallow, not much light will be reflected into the upwelling stream, and the component of the unpolarized light is therefore smaller (leaving the degree of polarization somewhat higher). Just the fact that the modeled depth did increase and showed an improvement over the radiance condition (that which is used in the optimization scheme) suggests polarization in a spectral sense or combined polarization and hyperspectral data will enhance the bathymetry retrieval in these very turbid water conditions.

IMPACT/APPLICATIONS

Determining bathymetry in shallow rivers has a direct impact on riverine Special Operations where knowing that a river is 0.2 meters versus 0.4 meters deep has an enormous impact. In these very turbid shallow waters the use of the active pulsed systems are likely to be constrained due to the large amount of scattering. However as demonstrated the use of polarization will likely improve the depth to which the bottom can be detected. This combined with the hyperspectral Look-Up-Tables or optimization schemes often used in bathymetry extraction offers a potential capability to extend passive sensor use. This has implications for the unmanned vehicles as well where space is insufficient for an active system but multispectral or even hyperspectral systems with polarization capabilities can enhance river bathymetry determinations.

TRANSITIONS

This research has been passed on to NAVAIR to assist in the decision to add polarization to the Joint Multi-Mission Electro-optic Sensor (JMMES) for MCM and shallow water activities (PMA 264, Mike Contarino and Jennifer Prentice). The model results will also be used to determine limits of turbid water bathymetry extraction in the 6.4 RTP "Feature Extraction and Simulation of River Dynamics using Satellite-Derived Information, POC Alan Weidemann".

RELATED PROJECTS

This project augments the following projects:

Lidar and hyperspectral remote sensing of the littoral environment (ONR/NRL 6.2; J. Bowles POC) which has a goal of combining active bathymetric lidar and hyperspectral imagery to retrieve optical properties, bottom reflectivity, and bathymetry in various coastal waters extending to the very shallow water.

Tactical UAV hyperspectral imagery for riverine special operations (ONR/NRL 6.2; A. Weidemann POC) which addresses retrieval of tactically significant environmental properties (including bathymetry) for rivers using hyperspectral imagery.

Feature Extraction and Simulation of River Dynamics using Satellite-Derived Information (SPAWAR 6.4; A. Weidemann POC) which addresses image product generation including bathymetry from airborne or satellite platforms.

REFERENCES

Lee, Z. P., K.L. Carder, R.F. Chen and T. G. Peacock, 2001. "Properties of the water column and bottom derived from AVIRIS data," *J. Geophys. Res.,* 106, 11639 – 11652.